Charged pion production in C+C and Ar+KCl collisions measured with HADES [1]

P. Tlustý[14], G. Agakishiev[8], A. Balanda[3,e], G. Bellia[1,a], D. Belver[15], A. Belyaev[6], A. Blanco[2], M. Böhmer[11], J. L. Boyard[13], P. Braun-Munzinger[4], P. Cabanelas[15], E. Castro[15], S. Chernenko[6], T. Christ[11], M. Destefanis[8], J. Díaz[16], F. Dohrmann[5], A. Dybczak[3], L. Fabbietti[11], O. Fateev[6], P. Finocchiaro[1], P. Fonte[2,b], J. Friese[11], I. Fröhlich[7], T. Galatyuk[4], J. A. Garzón[15], R. Gernhäuser[11], A. Gil[16], C. Gilardi[8], M. Golubeva[10], D. González-Díaz[4], E. Grosse[5,c], F. Guber[10], M. Heilmann[7], T. Hennino[13], R. Holzmann[4], A. Ierusalimov[6], I. Iori[9,d,†], A. Ivashkin[10], M. Jurkovic[11], B. Kämpfer[5], K. Kanaki[5], T. Karavicheva[10], D. Kirschner[8], I. Koenig[4], W. Koenig[4], B. W. Kolb[4], R. Kotte[5], A. Kozuch[3,e], A. Krása[14], F. Křížek[14], R. Krücken[11], W. Kühn[8], A. Kugler[14], A. Kurepin[10], J. Lamas-Valverde[15], S. Lang[4], J. S. Lange[8], K. Lapidus[10], T. Liu[13], L. Lopes[2], M. Lorenz[7], L. Maier[11], A. Mangiarotti[2], J. Marín[15], J. Markert[7], V. Metag[8], B. Michalska[3], J. Michel[7] D. Mishra[8], E. Morinière[13], J. Mousa[12], C. Müntz[7], L. Naumann[5], R. Novotny[8], J. Otwinowski[3], Y. C. Pachmayer[7], M. Palka[4], Y. Parpottas[12], V. Pechenov[8], O. Pechenova[8], T. Pérez Cavalcanti[8], J. Pietraszko[4], W. Przygoda[3,e], B. Ramstein[13], A. Reshetin[10], A. Rustamov[4], A. Sadovsky[10], P. Salabura[3], A. Schmah[4], R. Simon[4], Yu.G. Sobolev[14], S. Spataro[8], B. Spruck[8], H. Ströbele[7], J. Stroth[7,4], C. Sturm[7], M. Sudol[4], A. Tarantola[7], K. Teilab[7], M. Traxler[4], R. Trebacz[3], H. Tsertos[12], I. Veretenkin[10], V. Wagner[14], M. Weber[11], M. Wisniowski[3], J. Wüstenfeld[5], S. Yurevich[4], Y. Zanevsky[6], P. Zhou[5], P. Zumbruch[4]

(HADES collaboration)

[1] Istituto Nazionale di Fisica Nucleare - Laboratori Nazionali del Sud, 95125 Catania, Italy
[2] LIP-Laboratório de Instrumentação e Física Experimental de Partículas, 3004-516 Coimbra, Portugal
[3] Smoluchowski Institute of Physics, Jagiellonian University of Cracow, 30-059 Kraków, Poland
[4] Gesellschaft für Schwerionenforschung mbH, 64291 Darmstadt, Germany
[5] Institut für Strahlenphysik, Forschungszentrum Dresden-Rossendorf, 01314 Dresden, Germany
[6] Joint Institute of Nuclear Research, 141980 Dubna, Russia
[7] Institut für Kernphysik, Johann Wolfgang Goethe-Universität, 60438 Frankfurt, Germany
[8] II.Physikalisches Institut, Justus Liebig Universität Giessen, 35392 Giessen, Germany
[9] Istituto Nazionale di Fisica Nucleare, Sezione di Milano, 20133 Milano, Italy
[10] Institute for Nuclear Research, Russian Academy of Science, 117312 Moscow, Russia
[11] Physik Department E12, Technische Universität München, 85748 München, Germany
[12] Department of Physics, University of Cyprus, 1678 Nicosia, Cyprus
[13] Institut de Physique Nucléaire d'Orsay, CNRS/IN2P3, 91406 Orsay Cedex, France

[1]Contribution presented at the XLVII International Winter Meeting on Nuclear Physics, Bormio (Italy), Jan. 26-30, 2009

[14] Nuclear Physics Institute, Academy of Sciences of Czech Republic, 25068 Rez, Czech Republic
[15] Departamento de Física de Partículas, University of Santiago de Compostela, 15782 Santiago de Compostela, Spain
[16] Instituto de Física Corpuscular, Universidad de Valencia-CSIC, 46971 Valencia, Spain
[a] Also at Dipartimento di Fisica e Astronomia, Università di Catania, 95125 Catania, Italy
[b] Also at ISEC Coimbra, Coimbra, Portugal
[c] Also at Technische Universität Dresden, 01062 Dresden, Germany
[d] Also at Dipartimento di Fisica, Università di Milano, 20133 Milano, Italy
[e] Also at Panstwowa Wyzsza Szkola Zawodowa, 33-300 Nowy Sacz, Poland

Abstract

Results of a study of charged pion production in ^{12}C + ^{12}C collisions at incident beam energies of 1A GeV and 2A GeV, and ^{40}Ar + ^{nat}KCl at 1.76A GeV, using the spectrometer HADES at GSI, are presented. We have performed a measurement of the transverse momentum distributions of $\pi^{\pm}$ mesons covering a fairly large rapidity interval, in case of the C+C collision system for the first time. The yields, transverse mass and angular distributions are compared with a transport model as well as with existing data from other experiments.

1 Introduction

The study of particle production in nucleus-nucleus collisions at relativistic energies is essential for understanding the dynamics and the approach of the system towards equilibrium and the generation of flow phenomena, as well as for gaining information about the nuclear equation of state. In heavy-ion collisions, pion spectra and yields are affected by collective effects like thermalization, directed and elliptic flow, as well as by possible modifications of the properties of baryon resonances they stem from, in particular the Δ. The subtle interplay of these phenomena is indeed a challenge to theoretical interpretations.

Best suited for a description of all phases of the complex dynamics of heavy-ion reactions are transport models, based on microscopic kinetic theory. Transport models achieve a remarkable success in describing bulk properties of the interactions over a large energy and system size scale. At the same time, however, for special channels, problems are met in reproducing precisely the experimental data. For a recent comprehensive discussion of various differential pion observables and their comparison with model calculations in the region of 1A GeV see [1].

The High Acceptance Di-Electron Spectrometer (HADES) [2], is designed for high-resolution and high-acceptance dielectron spectroscopy in hadron-hadron, hadron-nucleus, and nucleus-nucleus reactions at beam energies in the range from 1A GeV to 2A GeV. For a detailed description of the device and recently performed experiments see [3].

In this paper, we discuss data on charged pions obtained from ^{12}C + ^{12}C collisions at 1A GeV and 2A GeV (recently published in [4]) and ^{40}Ar + ^{nat}KCl at 1.76A GeV. In case of the ^{12}C + ^{12}C

system, large intervals of rapidity and of centre-of-mass angle are covered for the first time. Our results are compared to UrQMD transport-model predictions and experimental data from other experiments.

2 Experiment

The presented data were collected under the LVL1 trigger condition which was based on a fast determination of the charged-particle multiplicity (M_{ch}) in the time-of-flight detectors. The condition $M_{ch} \geq 4$ for ^{12}C + ^{12}C and $M_{ch} \geq 16$ for ^{40}Ar + ^{nat}KCl was used.

In the first experiment, the collision system ^{12}C + ^{12}C at 2A GeV was studied with a beam intensity of $I_{beam} = 10^6$ particles/sec impinging on a two-fold segmented carbon target with thickness of $2 \cdot 2.5\%$ interaction length. In the second data taking period the ^{12}C + ^{12}C system was studied at 1A GeV. Then, for the first time, a high-resolution tracking mode exploiting also the outer MDC planes was available. In this measurement, a carbon beam of 10^6 particles/sec was focused onto a carbon foil of 3.8% interaction length. In the last experiment analyzed here, the four-fold segmented target was made of natural KCl and has a total interaction length of 3.05%. The ^{40}Ar beam intensity was about $6 \cdot 10^5$ particles/sec.

Particle identification in the HADES data analysis (for details see [2]) is based on Bayesian statistics. The method allows to evaluate the probability that the reconstructed track can be related to a certain particle species (e.g. proton, kaon, pion, electron, etc.). It combines several observables from various sub-detectors (e.g. time-of-flight, energy loss) via probability density functions determined for each observable and for all possible particle species. In our case, hadron identification has been performed using measured momenta and corresponding velocities computed by means of the time-of-flight. After the particle identification is done for all tracks, the resulting yields are corrected for efficiency and purity of the PID method, as well as for the detector and tracking efficiencies. The detection/tracking efficiency has been obtained from Monte Carlo simulated and reconstructed UrQMD events. Further experimental details can be found in [4, 5].

3 Results

3.1 Transverse-mass distributions

Figure 1 exhibits the measured and simulated transverse mass distributions of π^+ and π^- in different intervals of normalized rapidity y_0 for the reaction ^{40}Ar + ^{nat}KCl at 1.76A GeV.

The transverse mass distributions for all three data sets can be described by a single-exponential (^{12}C + ^{12}C at 1A GeV) or two-exponential (^{12}C + ^{12}C at 2A GeV and ^{40}Ar + ^{nat}KCl) functions.

As shown in [4], our data for ^{12}C + ^{12}C reactions are in agreement with the data measured by KaoS [6]. For ^{40}Ar + ^{nat}KCl at 1.76A GeV (see fig. 1) our data also agree with results from

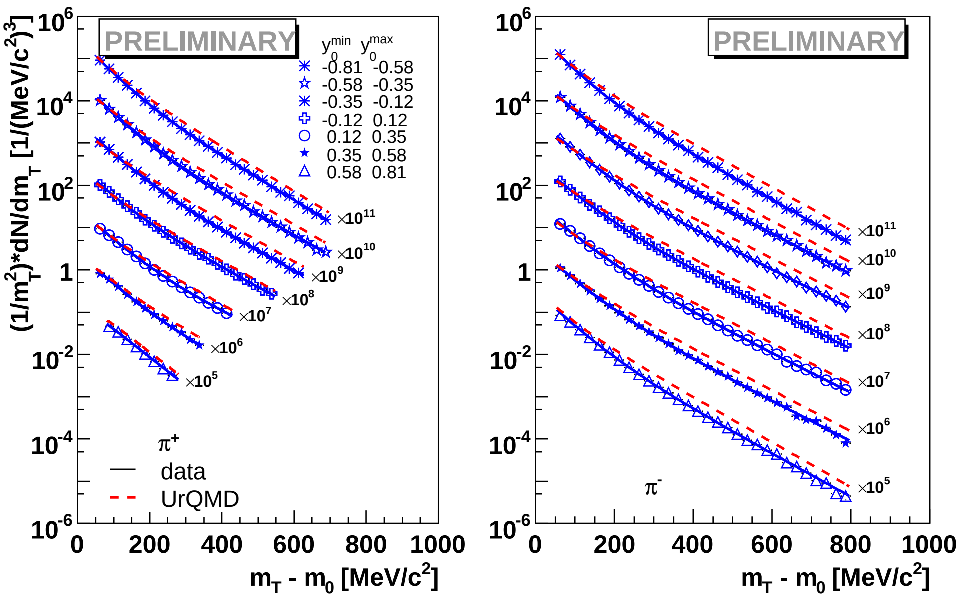

Figure 1: Transverse-mass distributions for positively (left) and negatively (right) charged pions in different slices of rapidity derived from the data in ^{40}Ar + ^{nat}KCl at 1.76A GeV (LVL1 "semi-central" events). Full lines show the results of fits to the data (symbols) using two exponential functions, while dashed lines show fits of the UrQMD distributions using the same function. Error bars (systematic and statistical ones) are not visible at this scale. Both data and UrQMD distributions are normalized to the number of LVL1 events.

the Ar+KCl at 1.8A GeV reaction [7]. As seen in fig. 1, the agreement of UrQMD simulations with our data is only qualitative. Both data sets for π^+ and π^- are described by two-exponential shapes. However, the UrQMD simulations show a much stronger stiff component at large momenta. In case of ^{12}C + ^{12}C at 1A GeV the agreement is much better, and both UrQMD and data exhibit a single-exponential shape. For ^{12}C + ^{12}C at 2A GeV, UrQMD predicts different spectral shapes - purely exponential as compared to the concave shape of the data [4]. Data of π^0 for ^{12}C + ^{12}C at 2A GeV also need only a single-exponential fit [8]. This may indicate differences in the reaction dynamics of charged and neutral π mesons, not described properly in the employed transport code.

3.2 Multiplicities

Pion yields (N_π) per reaction (under the LVL1 trigger condition) within the HADES acceptance region and extrapolated to full phase space are presented in Table 1. The last column shows the multiplicities per participant, obtained by dividing the yields with the averaged number of participating nucleons in the LVL1-triggered reactions estimated from simulations.

The systematic error of the measured yield due to uncertainties in the detection/reconstruction/identification efficiency is estimated as 5%, based on a comparison of measurements in the six independent HADES sectors. The extrapolation of the yields to full phase space is based on

Table 1: Production yields of $\pi^{\pm}$ per reaction under LVL1 trigger condition. N_π and $N_\pi(4\pi)$ are the measured and 4π extrapolated yields, respectively, and $N_\pi(4\pi)/N_{part}$ is the yield per participant averaged for π^+ and π^-. The statistical errors are negligible. Shown are the systematic errors due to the various efficiency corrections and the 4π extrapolation (see text).

system	energy (A GeV)		N_π	$N_\pi(4\pi)$	$N_\pi(4\pi)/N_{part}$ $(\cdot 10^3)$
^{12}C + ^{12}C	1	π^+	0.36±0.02	0.46±0.03±0.05	55±3±5±4
		π^-	0.38±0.02	0.49±0.03±0.05	
^{12}C + ^{12}C	2	π^+	0.77±0.04	1.19±0.06±0.11	$147\pm7\pm13\,^{+0}_{-21}$
		π^-	0.82±0.04	1.28±0.06±0.12	
^{40}Ar + ^{nat}KCl	1.76	π^+	1.67±0.08	3.00±0.15±0.27	89±4±8±6
		π^-	2.08±0.10	3.84±0.19±0.34	

the integration of the simulated rapidity distributions and normalized to the data in the rapidity range covered by HADES. Varying the input conditions of the simulations, the differences between the rapidity distributions give us an estimate of the systematic error of the yield extrapolations of 9%. The last systematic error of the resulting $\pi^{\pm}$ multiplicity per participant (last column in Table 1) stems from uncertainties connected with the determination of the average number of participating nucleons using UrQMD simulation (7%).

3.3 Angular distributions

The measured centre-of-mass polar angular distributions of pions produced in ^{40}Ar + ^{nat}KCl collisions at 1.76A GeV are exhibited in fig. 2. For the symmetric collision system the polar distributions in the center-of-mass system can be fitted with the expression $dN/d(\cos\theta_{cms}) \propto (1 + A_2\cos^2\theta_{cms})$. The parameter A_2 characterizes the anisotropy of the pion source. As visible in fig. 2, the data show strong anisotropies quantified by $A_2 = 0.75 \pm 0.11$. Similar results are observed in the ^{12}C + ^{12}C system, where $A_2 = 0.88 \pm 0.12$ and 1.19 ± 0.16 for beam energies of 1A GeV and 2A GeV, respectively. The two closest systems studied most comprehensively in this respect are Ar+KCl at 1.8A GeV [7] and Ca+Ca at 1.93A GeV [1]. In both cases similar momentum-averaged anisotropies were observed, with values of $\langle A_2 \rangle = 0.5 - 0.6$. Also the UrQMD simulations exhibit similar results for all three systems.

4 Summary

In summary, the charged-pion characteristics in the reactions ^{12}C + ^{12}C at 1A GeV and 2A GeV, and ^{40}Ar + ^{nat}KCl at 1.76A GeV have been measured in detail with the HADES spectrometer. In case of ^{12}C + ^{12}C reactions our data were obtained for the first time in a large acceptance region,

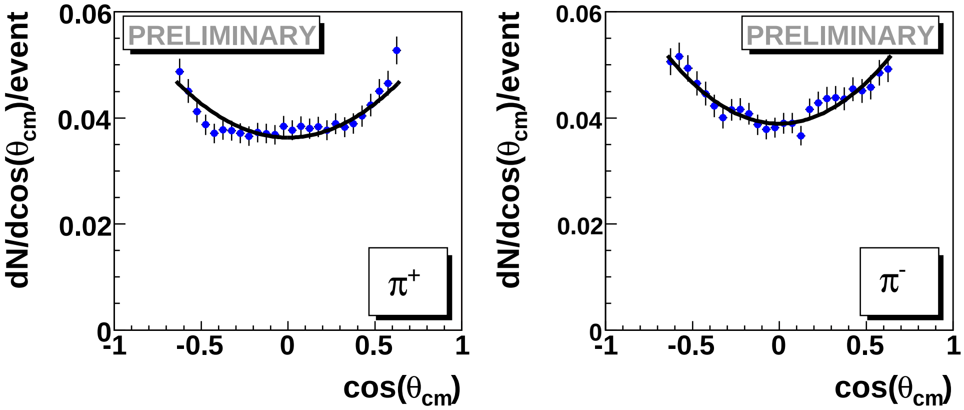

Figure 2: Polar angle distribution in the center-of-mass system of positively (left) and negatively (right) charged π mesons produced in ^{40}Ar + ^{nat}KCl collisions at 1.76A GeV for the LVL1 (semicentral) events. Pions with center-of-mass momenta 200 - 800 MeV/c have been selected. The full lines show the fit as described in the text.

which allowed for the measurement of pion anisotropy and consequently for a more reliable extrapolation of the yields to full solid angle. The found results are in good agreement with data obtained with previous experiments. A comparison with the results on neutral pions and the UrQMD predictions for ^{12}C + ^{12}C at 2A GeV suggests differences in the reaction dynamics of charged and neutral π mesons, not yet described by transport codes.

Acknowledgments

The HADES collaboration gratefully acknowledges the support by BMBF grants 06MT238, 06TM970I, 06GI146I, 06F-140, 06FY171, and 06DR135, by DFG EClust 153 (Germany), by GSI (TM-KRUE, TM-FR1, GI/ME3, and OF/STR), by grants GA AS CR IAA100480803 and MSMT LC 07050 (Czech Republic), by grant KBN 5P03B 140 20 (Poland), by INFN (Italy), by CNRS/IN2P3 (France), by grants MCYT FPA2006-09154, XUGA PGID IT06PXIC296091PM and CPAN CSD2007-00042 (Spain), by grant FTC POCI/FP /81982 /2007 (Portugal), by grant UCY-10.3.11.12 (Cyprus), by INTAS grant 06-1000012-8861 and EU contract RII3-CT-2004-506078.

References

[1] W. Reisdorf *et al.*, Nucl. Phys. A 781 (2007) 459.

[2] G. Agakishiev, arXiv:0902.3478v1 [nucl-ex], Eur. Phys. J. A, in print.

[3] I. Fröhlich *et al.*, contribution in this volume, and references herein, arXiv:0906.0091 [nucl-ex].

[4] G. Agakishiev *et al.*, Eur. Phys. J. A 40 (2009) 45.

[5] F. Krizek *et al.*, Int. J. Mod. Phys. A 24 (2009) 603.

[6] F. Laue *et al.*, Eur. Phys. J. A 9 (2000) 397; C. Sturm, PhD thesis, TU Darmstadt, 2001, http://elib.tu-darmstadt.de/diss/000166/.

[7] R. Brockman *et al.*, Phys. Rev. Lett., 53 (1984) 2012.

[8] R. Averbeck *et al.*, Z. Phys. A 359 (1997) 65.